Logographic Kanji versus Phonographic Kana in Literacy Acquisition

How Important Are Visual and Phonological Skills?

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It is well-established that phonological skills are important for literacy acquisition in all scripts. However, the role of visual skills is less well understood. For logographic scripts in which a symbol represents a whole word or a meaningful unit, the importance of visual memory in literacy acquisition might be expected to be high because of the visual complexity of logographic characters, but in fact its role remains poorly understood. The Japanese writing system uses both phonographic "Kana" and logographic "Kanji" scripts concurrently and thus allows for the assessment of the contribution of phonological and visual processing to literacy acquisition in these two different scripts in the same language. We tested 74 Japanese children (39 second graders and 35 fourth graders) on a range of literacy, sensory, and cognitive tasks. We found that Kana literacy performance was significantly predicted by low-level sensory processing (both auditory frequency modulation sensitivity and visual motion sensitivity) as well as phonological awareness, but not by visual memory. This result is largely consistent with previous studies in other phonographic scripts such as English. In contrast, Kanji literacy performance was strongly predicted by visual memory (particularly visual long-term memory), but not by either low-level sensory processing or phonological awareness. Our results show differences in the skills that predict literacy performance in phonographic Kana and logographic Kanji, as well as providing experimental evidence that visual memory is important when learning Kanji. Therefore, children's literacy problems and remediation programs should be considered in the context of the script in which children are learning to read and write.

Key words: logographic versus phonographic; visual long-term memory; phonological awareness; low-level sensory processing; reading and writing; Japanese

Introduction

The acquisition of literacy skills varies according to writing systems. These can be broadly divided into phonographic and logographic scripts, and the Japanese writing system uses both scripts concurrently (Fig. 1). Phonographic systems, in which a symbol is mapped onto a sound unit, use alphabetic or syllabic scripts, such as English or Japanese

"Kana," respectively. Logographic systems in which a symbol is mapped onto either a word or morpheme (a meaningful unit) are exemplified by Chinese and by Japanese "Kanji" scripts. There is now a general consensus that phonological skills, such as phonological awareness and phonological short-term memory, play essential roles in reading acquisition in both phonographic (Bradley & Bryant, 1983; Bryant, Maclean, Bradley, & Crossland, 1990; Gathercole, Hitch, Service, & Martin, 1997; Muter, Hulme, Snowling, & Stevenson, 2004) and Chinese logographic writing systems (Ho & Bryant, 1997; Siok & Fletcher,

私は猫が大好きです。

Figure 1. An example of Japanese sentence. Underlined characters are logographic Kanji and the rest are phonographic Kana (= I like cats very much).

2001). However, phonological awareness seems to contribute to literacy performance to a lesser extent in logographic scripts (McBride-Chang, Bialystok, Chong, & Li, 2004; McBride-Chang *et al.*, 2005; Tan, Spinks, Eden, Perfetti, & Siok, 2005). In contrast, the importance of visual skills in learning to read logographic scripts is still debated. Inconsistent results have been obtained about correlations between visual skills & Chinese reading performance (evidence *for* is provided by Everatt, Jeffries, Elbeheri, Smythe, & Veii, 2006; Ho, Chan, Lee, Tsang, & Luan, 2004; Huang & Hanley, 1995; and evidence *against* is provided by Hu & Catts, 1998; McBride-Chang & Kail, 2002). Therefore, in this study we aimed to clarify the contribution(s) of phonological and visual skills (particularly those involving visual memory) to literacy acquisition by comparing Japanese phonographic Kana and logographic Kanji.

Each Japanese Kana letter represents one mora, which is a subsyllabic unit of sound in Japanese. A mora usually consists of a consonant and a vowel (e.g., "か" represents the mora/ka/). The letter-to-sound correspondence is highly regular and consistent, nearly one-to-one, with minor exceptions. Kana is subdivided into Hiragana and Katakana; Hiragana is usually used for morphological endings and function words, while Katakana is used to write loan words, which are words taken directly into Japanese from another language with very little translation. At school, all 92 Kana letters (46 letters for Hiragana and 46 for Katakana) are introduced to children before Kanji, usually at the beginning of first grade (at the age of 6–7 years). Since Kana has a highly regular orthography, most Japanese children master Kana reading quickly even before the onset of the formal education, but Kana writing is not acquired so fast (Shimamura & Mikami, 1994).

Unlike Kana, Kanji characters are visually complex and usually have multiple pronunciations depending on the context. Although a word can be represented by a single Kanji character, most Kanji words comprise more than two characters, forming so-called compound Kanji words. Thus, the correct pronunciations of Kanji words, especially compound Kanji words, are determined at the whole-word level in a similar fashion to learning to read English exception words such as *yacht*. This unique linguistic property in Kanji differentiates Japanese Kanji from the Chinese logographic system, in which each character has only one or two pronunciations.

Japanese children normally start learning Kanji after having learnt Kana. They are expected to learn 80 Kanji characters by the end of first grade, and by the end of sixth grade they should have mastered 1006 Kanji characters along with 2005 possible pronunciations for these characters (Kess & Miyamoto, 1999). Thus learning Kanji makes intensive demands on memory capacity in both the visual and phonological domains. This is reflected in the higher prevalence of literacy problems in Kanji than in Kana among Japanese children (Uno, 2004).

Consistent with studies in other phonographic scripts, phonological awareness (Hara, 1998) and phonological short-term memory (Kobayashi, Haynes, Macaruso, Hook, & Kato, 2005) are important in learning to read Kana. However, few studies have attempted to elucidate the relationship between phonological skills and literacy development in Kanji. Clearly, the multiple possible pronunciations of each Kanji character demand a retentive phonological memory. As to auditory sensory processing, its contribution to the acquisition of Kana or Kanji remains unknown. However, in phonographic scripts children's sensitivity to auditory frequency modulations (Talcott *et al.*, 2002; Witton, Stein, Stoodley, Rosner, & Talcott, 2002), auditory

amplitude modulations (Goswami *et al.*, 2002) and rhythm (Anvari, Trainor, Woodside, & Levy, 2002) are related to their phonological and literacy skills. Similarly, reading performance in logographic Chinese is predicted by auditory frequency and tone discrimination tasks (Meng *et al.*, 2005). However, Chinese is a far more tonal language than Japanese, and thus basic auditory processing may be more important for literacy acquisition in Chinese than in Japanese. To date, no study has investigated the relationship between auditory processing and literacy development in Japanese.

Because of the visual complexity of Kanji, it is likely that visual memory plays an important role in literacy acquisition of this logographic writing system. Yet results of previous studies of logographic reading in Chinese have been inconsistent (Siok & Fletcher, 2001). In phonographic scripts, only a few studies have shown a close relationship between visual memory and reading English (Watson *et al.*, 2003). Recent research, however, has shown that Japanese (Uno, Kaneko, Haruhara, & Kaga, 2000) and Chinese (Ho, Chan, Tsang, Lee, & Chung, 2006) dyslexic children seem to have problems with visual long-term memory. In addition, visual-orthographic skills are impaired in Chinese individuals with dyslexia (Ho, Chan, Lee, Tsang, & Luan, 2004). Unlike letters in phonographic systems, most logographic characters can be visually decomposed into a semantic radical on the left and a phonetic radical on the right, and this sublexicality is thought of as orthography in logographic systems. But phonetic radicals do not always provide reliable information about the pronunciation of logographic characters in either Chinese or Japanese (Saito, Kawakami, & Masuda, 1995). For this reason, it is most likely that skilled Japanese readers showed negative priming effects in phonological and visual-orthographic modalities during a semantic judgment task of Kanji words (Sakuma, Sasanuma, Tatsumi, & Masaki, 1998). These results suggest the strong involvement of visual-orthographic processing in reading logographic Kanji.

One specific measure of low-level visual sensory processing, namely visual motion sensitivity, has been shown to correlate with orthographic skills in both phonographic (Boets, Wouters, van Wieringen, & Ghesquiere, 2006; Talcott *et al.*, 2002) and logographic writing systems (Meng, Zhou, Zeng, Kong, & Zhuang, 2002). Visual motion sensitivity is thought to be a function of the visual magnocellular system, and it may play a role in focusing visual attention and controlling eye movements during reading for sequences of letters and words (Stein, 2003). Although it is controversial as to what extent visual motion sensitivity is causally related to literacy performance in phonographic scripts such as English (Hutzler, Kronbichler, Jacobs, & Wimmer, 2006), little is known about whether low-level visual sensory processing is important for the acquisition of orthographic and literacy skills in phonographic Kana with its extremely regular orthography or in logographic Kanji.

The present study therefore aimed to investigate the contribution of auditory-phonological and visual-orthographic skills to the acquisition of phonographic Kana and logographic Kanji in Japanese children. Our main hypothesis is that, like other phonographic scripts, Kana acquisition will depend on auditory-phonological skills whereas Kanji acquisition will be more affected by visual-orthographic skills, particularly visual long-term memory. Although previous studies using the Rey–Osterrieth Complex Figure test (ROCF) have shown the importance of visual long-term memory for literacy skills in Kanji (Uno, Kaneko, Haruhara, & Kaga, 2000), this test measures many different cognitive abilities in children, such as visuospatial perception, visuospatial construction, and visuospatial memory as well as executive functions (planning and organizational skill) (Watanabe *et al.*, 2005). Hence, the ROCF does not clearly identify which visual-cognitive components contribute to learning Kanji. We have therefore developed a novel recognition task that focuses on the capacity to store visual information in long-term memory and retrieve

it in order to understand its specific contribution to Kanji acquisition. In addition, our results should increase our understanding of which abilities are universally important for the development of literacy skills, irrespective of the script or writing system.

Methods

Participants

Seventy-four (74) Japanese children in a state primary school were tested, of whom 39 were second graders (7–8 years of age) and 35 were fourth graders (9–10 years of age). This primary school was located in a middle-class suburban community in Shizuoka prefecture. All children were native Japanese speakers and had no history of neurobiological disorders. Informed parental consent was obtained prior to testing. They had not started learning English reading (or other languages) at the time this study was conducted.

Measures

An extensive battery of intelligence, literacy, sensory, and cognitive tasks was administered to each child individually. None of the tasks in this study have been standardized on a large number of children; thus, we used raw scores and partialled out the effects of age in the analyses.

Nonverbal Intelligence

Raven's Colored Progressive Matrices (Raven, Raven, & Court, 1998) were used to index nonverbal intelligence. The children's nonverbal IQ performance fell within the average range using age-referenced norms at a cutoff level of 1.5 standard deviations (Uno, Shinya, Haruhara, & Kaneko, 2005). Originally, 77 children participated in this study, but 3 children who did not meet this criterion were removed from the data set, resulting in a sample size of 74 children.

Reading and Writing Tasks

Because of the lack of standardized tests for reading and writing in Japanese, new reading and writing tasks were developed to measure children's literacy skills in Kana and Kanji. For reading, the children were asked to read words aloud as accurately and quickly as possible. The writing task was to write down words dictated to them by the experimenter. For each reading and writing task, 20 Kana words were selected from official textbooks used at state primary schools in Japan for first to sixth graders. These included several sounds which are specific to Japanese, such as contracted, double consonant, and long vowel sounds. Likewise, the Kanji words were chosen from the national survey on the "acquisition of Kanji at each grade level" (Japan Foundation for Educational and Cultural Research, 1998). For these Kanji tasks, 60 words were used for the reading task and 40 words for the writing task. Both one-character Kanji words and two-character (compound) Kanji words were arranged in such a way that the difficulty level increased from first to sixth grade. In addition, each set of Kanji words included both visually simple and complex characters, whose complexity was defined by the number of strokes composing the character. Because the number of characters to be mastered for Kanji (640 characters up to the end of fourth grade) is far greater than that for Kana (only 92 characters for Kana), the Kanji tasks included more words than did the Kana tasks.

To measure children's sensory abilities, we used auditory frequency modulation, visual coherent motion, and visual form tasks. All sensory tasks used a 1-up, 2-down adaptive staire procedure.

Auditory Frequency Modulation Task

The frequency modulation task was designed to measure low-level auditory processing (Witton *et al.*, 1998). Children were asked to discriminate between a pure 1-kHz tone and a 1-kHz tone that was frequency modulated

at a rate of 2 Hz; the stimuli lasted 1000 ms and the interstimulus interval (ISI) was 500 ms. On each trial, two birds on a computer screen sang the tones one after the other. The children, wearing headphones at a comfortable hearing level (60 dB) in a quiet room, were asked to report verbally which bird, the first or second, had a wobbly voice (the frequency-modulated tone). The detection threshold was estimated as the mean of 16 reversals.

Visual Coherent Motion and Visual Form Tasks

The two low-level visual sensory tasks, the visual motion and visual form tasks, were designed to measure dynamic and static visual processing, respectively (Hansen, Stein, Orde, Winter, & Talcott, 2001). For the visual motion task, children viewed two rectangular patches, each of which contained 300 moving dots. In one patch, the dots moved randomly; in the other, a proportion of the dots moved in the same direction coherently. The children were asked to press the key on the side corresponding to the patch that contained the dots that were moving coherently. Coherent motion was varied to each child's motion-detection threshold by the 1-up, 2-down adaptive staircase procedure, with a constant starting value of 80% coherence. The coherence threshold, indexing the children's visual motion sensitivity, was estimated from the geometric mean of 12 reversals.

For the visual form task, the children viewed two rectangular patches, each of which contained 300 randomly oriented stationary short lines. They were asked to press the key on the side where a subset of the oriented lines formed concentric circles. This subset was then reduced in number according to the 1-up, 2-down staircase. The form threshold was estimated as the mean of 12 reversals.

To measure children's cognitive abilities, we used a battery of phonological, orthographic, and visual tasks. All of these tasks, except for the visual short-term memory task, were developed specially for this study.
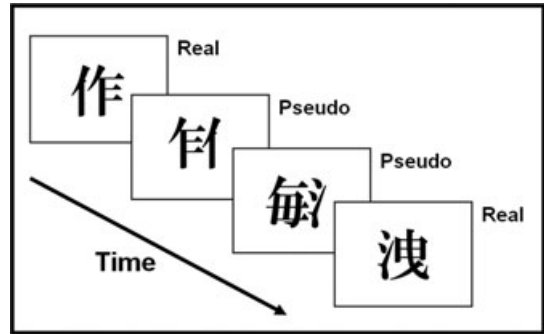

Figure 2. The radical position task (orthographic processing). Children were asked to judge whether a presented character was real or not by pressing the appropriate key. Pseudocharacters were made by reversing radicals between left and right, as shown by the second and third stimuli from the top.

Phonological Tasks

Two phonological tasks were used. The mora deletion task, using "mora" as a subsyllabic unit of sound in Japanese, was a measure of phonological awareness. The nonword repetition task, modified from the original version by Saito (Saito, Saito, & Yoshimura, 2000), was designed to measure children's phonological short-term memory. In the mora deletion task, a set of 25 nonwords, whose length varied from 2 to 6 moras, were presented auditorily. The children were asked to delete one mora (e.g., /ka/) from the spoken nonword (e.g., /sa-ka-jo/). In the nonword repetition task, the children were asked to repeat the nonword immediately after they listened to it. Nonword repetition (Gathercole, Baddeley, & Emslie, 1994) has been used intensively in studying reading in English and is closely related to children's reading performance (Hulslander *et al.*, 2004). For both tasks, the difficulty was increased by increasing the number of mora. The number of correct nonwords repeated by the child was recorded for each task.

Orthographic Task

To measure children's orthographic knowledge, as indicated by their awareness of the internal structure of Kanji, we developed the radical position task (Fig. 2). A randomly mixed
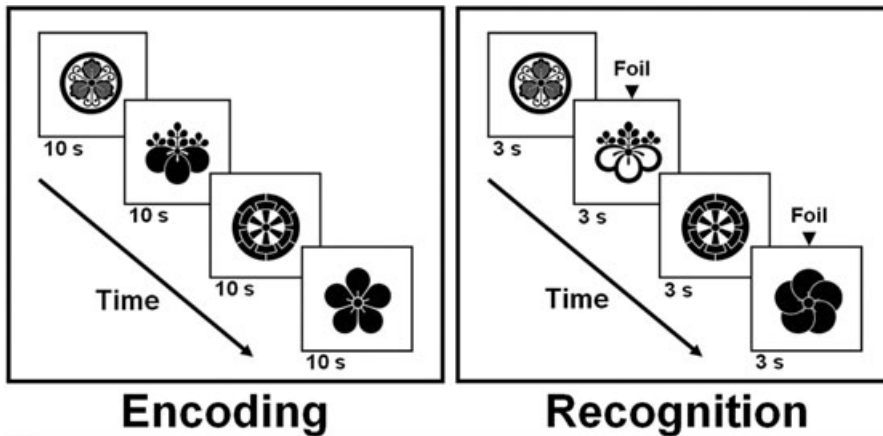
Figure 3. Visual long-term memory task. During the encoding phase, 20 target stimuli were presented successively (10 sec for each) on a computer screen. For the recognition test (2 hr later), the target stimuli and visually similar foils were randomly and repeatedly presented (3 sec for each), and children were asked to press a key when they thought they had seen the stimulus 2 hr earlier.

set of 40 real Kanji characters and 43 pseudo Kanji characters was presented sequentially on a computer. The pseudocharacters were constructed by reversing the position of the radicals between the left and right. The children were asked to judge whether a presented character was real or not by pressing the appropriate key. Although the real Kanji characters in this task had not been explicitly taught to either group of children, all the left radicals used in this task were familiar to both groups. This was possible because there are only 214 radical elements in Kanji characters and different combinations of these radicals generate an enormous number of Kanji characters. Hence, children theoretically ought to be able to recognize real Kanji characters merely by detecting a left radical on the left side. The task was self-paced by the children, although they were encouraged to proceed as quickly as possible. To perform this task well, the children needed both to understand the internal structure of radicals and to efficiently encode the radical position visually.

Short-Term and Long-Term Visual Memory Tasks

Children's visual memory capacity was measured using both short-term and long-term memory tasks. As a visual short-term memory task, the Visual Patterns Test, which involves no sequencing processing, was used (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999). Children were presented with a matrix in which half of the squares were black and half white for 3 sec. They were then asked to reproduce the pattern of black squares on the answer sheet by ticking them off with a pen. The difficulty was increased by increasing the number of both black and white squares in the matrix.

To measure visual long-term memory, we developed a new visual long-term memory task (Fig. 3), which used Japanese crests, "Kamon," as visual stimuli. At the beginning of the testing session, the children were instructed to memorize 20 target stimuli that would be presented successively (10 sec for each stimulus) on a computer screen for the later recognition test. At the end of the testing session (approximately 2 hr later), 20 target stimuli and 20 foils, which were visually similar to the target stimuli, were presented for 3 sec per stimulus, and the children were asked to press a key if they thought they had seen the stimulus 2 hr ago. The stimuli were randomly presented and repeated twice in order to reduce false alarms to an acceptable level. To perform this recognition task

TABLE 1. Descriptive Statistics for the Second and Fourth Graders

Measures	Second graders ($N = 39$)		Fourth graders ($N = 35$)	
	Mean	(SD)	Mean	(SD)
Age (months)	96.53	(5.48)	119.49	(3.97)
Literacy				
Kana reading (%)	98.13	(2.93)	99.71	(1.69)
Kana writing (%)	94.75	(5.06)	99.43	(2.65)
Kanji reading (%)	45.12	(10.37)	92.76	(7.40)
Kanji writing (%)	34.17	(11.49)	72.86	(11.60)
Nonverbal IQ				
Raven's Progressive Matrices (max = 36)	27.67	(4.32)	32.76	(1.97)
Sensory				
Frequency modulation (%)[a]	1.49	(0.49)	1.41	(0.86)
Visual motion (%)[a]	9.68	(2.44)	9.22	(3.30)
Visual form (%)[a]	31.55	(4.96)	23.80	(5.69)
Cognitive				
Mora deletion (max = 25)	15.02	(4.41)	20.54	(2.47)
Nonword repetition (max = 40)	20.00	(3.97)	26.40	(4.53)
Radical position (%)	56.99	(10.87)	85.84	(7.21)
Visual Patterns Test (max = 42)	12.33	(3.11)	16.91	(2.51)
Visual LTM (%)	49.42	(12.01)	69.07	(8.83)

Abbreviation: LTM = long-term memory.

[a](%) threshold (%) acuracy.

Results

Table 1 shows the descriptive statistics for the Japanese children (second and fourth graders). Even in the second graders, Kana reading performance was very high (at ceiling), confirming that reading Kana is mastered before formal school education starts (Shimamura & Mikami, 1994). Therefore, we did not further analyze the Kana reading data but used only three dependent variables: Kana writing (only for second graders), Kanji reading, and Kanji writing.

Partial correlation analysis controlling for age (Table 2) showed that Kana writing significantly correlated with performance on the Raven's matrices, frequency modulation, visual motion, mora deletion, nonword repetition, and radical position tasks, but not with the visual memory tasks. Like Kana writing performance, both Kanji reading and Kanji writing correlated with the Raven's matrices, mora deletion, nonword repetition, and radical position tasks, but unlike Kana, strong and significant correlations were found with the visual short-term and long-term memory tasks.

Which Processing Skills Predict Kana Acquisition?

The Kana writing data were negatively skewed, so the data were power transformed; this showed that the data were dichotomous. Therefore we used logistic regression analysis. The second graders were subgrouped into good ($N = 24$) or poor ($N = 15$) Kana writing groups. Poor Kana writers' accuracy rates were 1 standard deviation below the mean of the second graders' performance. These subgroups significantly differed from

TABLE 2. Correlation Analyses between Literacy Measures and Sensory/Cognitive Measures (Controlling for Age)

Measures	Kana writing ($N = 39$)	Kanji reading ($N = 74$)	Kanji writing ($N = 74$)
Raven's matrices	0.58**	0.43**	0.40**
Frequency modulation	−0.63**	0.02	−0.27
Visual motion	−0.52**	−0.02	−0.19
Visual form	−0.17	−0.12	−0.23
Mora deletion	0.60**	0.38*	0.34*
Nonword repetition	0.61**	0.50**	0.37*
Radical position	0.74**	0.59**	0.57**
Visual Patterns	0.19	0.43**	0.60**
Visual LTM	0.14	0.51**	0.78**

Note: The Kana writing data are based on only the second graders' performance ($N = 39$), and nonparametric correlation analysis was performed.

Abbreviation: LTM = long-term memory.

$^*P < 0.05$; $^{**}P < 0.01$ (2-tailed).

each other in their performance on the Kana writing task ($P < 0.01$, as determined by the Mann–Whitney U test).

In the logistic regression analyses, we tested five models, each of which controlled for nonverbal IQ (Raven's matrices) and included one of the other independent measures, which showed significant correlations with Kana writing; these included the frequency modulation, visual motion, mora deletion, nonword repetition, and radical position tasks. The co-linearity diagnostics showed a low variance inflation factor (VIF) for each measure in each model (VIFs < 1.3), indicating that there was no problem of multicollinearity in these five models (Allison, 1999). Table 3 shows the descriptive statistics for the good and poor Kana writers and the results of the logistic regression analyses with odds ratios and 95% confidence intervals of the odds ratios. In logistic regression analyses, if there is group difference on the measure concerned, the odds ratio will be significantly larger or smaller than 1.0 (indicating no group difference). After controlling for the Raven's scores, the frequency modulation, visual motion, and mora deletion tasks strongly differentiated the two groups, with odds ratios of 8.64, 3.59, and 0.69, respectively. In other words, when the detection threshold in these low-level sensory processing tasks increased (i.e., the sen-

sitivity to low-level sensory stimuli decreased), the likelihood of being a poor writer in Kana increased significantly. Similarly, when the score in the mora deletion task increased, the likelihood of being a poor writer in Kana decreased significantly (Note: the odds ratio was smaller than 1). The nonword repetition and radical position task predicted Kana writing less strongly.

Which Processing Skills Predict Kanji Reading and Writing Acquisition?

Our main interest in this study was to highlight the similarities and differences in literacy acquisition between phonographic Kana and logographic Kanji. So we combined the data for the Kanji performance of the second and fourth graders and removed the effect of age using multiple regression analyses. The children's age and their Raven's matrices scores were entered as Step 1 and Step 2, respectively, and then one of the other independent measures that correlated with Kanji measures was entered as the final step (Table 4). As would be expected, the child's age or grade was important for both Kanji reading and Kanji writing, accounting for 84.4% ($\Delta F = 388.13, P < 0.01$) and 78.4% ($\Delta F = 260.88, P < 0.01$) of the variance, respectively. This can be partially

TABLE 3. Descriptive Statistics for Good and Poor Kana Writers and the Logistic Regression Analyses Predicting the Success of Kana Writing

Models	Mean (SD)			Odds ratio (95% C.I.)	$P<$
	Good ($N = 24$)	Poor ($N = 15$)	$P<$		
Model 1					
Raven	28.87	26.96	0.01	0.88 (0.79–0.98)	0.05
	(3.06)	(4.07)			
FM	1.25	1.92	0.01	8.64 (1.59–47.10)	0.01
	(0.45)	(0.40)			
Model 2					
Raven				0.87 (0.79–0.97)	0.05
Visual motion	8.99	12.54	0.01	3.59 (1.34–9.65)	0.01
	(2.02)	(3.29)			
Model 3					
Raven				0.90 (0.83–0.98)	0.05
Mora deletion	17.04	13.20	0.01	0.69 (0.68–0.89)	0.01
	(4.07)	(3.59)			
Model 4					
Raven				0.89 (0.81–0.97)	0.05
Nonword repetition	21.13	18.33	0.01	0.82 (0.66–0.96)	0.05
	(3.88)	(3.60)			
Model 5					
Raven				0.92 (0.84–1.02)	NS
Radical position	62.21	48.24	0.01	0.88 (0.79–0.97)	0.05
	(8.96)	(11.98)			

Note: Units are as in Table 1.
Abbreviations: FM = frequency modulation; NS = nonsignificant.

TABLE 4. Summary of Multiple Regressions Predicting Literacy Measures in Kanji (Controlling for Age and Raven Score)

Step	Measures	Literacy measures (ΔR^2)	
		Kanji reading ($N = 74$)	Kanji writing ($N = 74$)
1	Age	0.844**	0.784**
2	Raven score	0.028**	0.024*
3	Mora deletion	0.006	0.008
	Nonword repetition	0.029**	0.025*
	Radical position	0.032**	0.054**
	Visual patterns	0.016*	0.059**
	Visual long term-memory	0.021*	0.097**

*$P < 0.05$; **$P < 0.01$ (two-tailed).

attributed to the Japanese national curriculum: children continue to learn new Kanji characters systematically throughout their primary school education. Nonverbal IQ as measured by Raven's matrices explained an additional 2.8% ($\Delta F = 13.60$, $P < 0.01$) and 2.4% ($\Delta F = 8.77$, $P < 0.05$) of the variance in Kanji reading and Kanji writing, respectively.

After controlling for age and nonverbal IQ, Kanji reading was best predicted by the radical position task, which accounted for an additional 3.2% ($\Delta F = 23.21$, $P < 0.01$) of the variance, followed by the nonword repetition,

visual long-term memory, and visual pattern tasks; these accounted for an additional 2.9% ($\Delta F = 19.91$, $P < 0.01$), 2.1% ($\Delta F = 12.98$, $P < 0.05$), and 1.6% ($\Delta F = 9.89$, $P < 0.05$) of the variance, respectively. Kanji writing was best predicted by the visual long-term memory task, which accounted for an additional 9.7% ($\Delta F = 71.39$, $P < 0.01$) of the variance, followed by the visual pattern, radical position, and nonword repetition tasks; these accounted for 5.9% ($\Delta F = 30.67$, $P < 0.01$), 5.4% ($\Delta F = 27.33$, $P < 0.01$), and 2.5% ($\Delta F = 8.87$, $P < 0.05$) of the variance, respectively. Although the mora deletion task was correlated with both Kanji reading and Kanji writing, it was not a significant predictor of Kanji performance when the effect of nonverbal IQ was removed.

Discussion

Our main aim in this study was to investigate similarities and differences in the skills that predict reading and writing in phonographic Kana and logographic Kanji. Our results showed that Kana writing was strongly predicted by low-level sensory processing (in both auditory and visual modalities) and phonological awareness, but not by visual memory, whereas Kanji measures were strongly predicted by visual memory measures, particularly visual long-term memory, but not by either low-level sensory processing or phonological awareness. Another important finding was that both orthographic processing and phonological short-term memory predicted literacy skills in both Kana and Kanji. The results for phonographic Kana are largely consistent with previous studies on reading in other phonographic scripts. But for learning logographic Kanji, visual memory is clearly most important.

Our behavioral results are corroborated by a recent functional magnetic resonance imaging (fMRI) study, which demonstrated that reading Kana and Kanji rely upon some common neural circuits, but differences between the scripts are reflected in greater activation of the left inferior parietal cortex for Kana and in greater activation of the right fusiform area for Kanji (Nakamura, Dehaene, Jobert, Bihan, & Kouider, 2005). The left inferior parietal cortex especially the left supramarginal gyrus, is thought to be involved in phonological storage (Pugh *et al.*, 2000) and the right fusiform gyrus is specifically activated by face perception (Kanwisher, McDermott, & Chun, 1997) and object identification (Vandenbulcke, Peeters, Fannes, & Vandenberghe, 2006). Thus, phonographic Kana may require more phonological processing than logographic Kanji, whereas Kanji may place more visual processing demand than Kana or other phonographic scripts.

Visual-Orthographic Skills

Children's visual long-term memory ability appears to be a robust and unique predictor of their Kanji performance, particularly of Kanji writing. This result is not surprising on account of the visual complexity of Kanji characters, but this study was the first to test children's visual long-term (i.e., recognition) memory experimentally. The results suggest that visual long-term memory is very important for reading and writing logographic characters.

Visual long-term memory has previously been shown to be impaired in dyslexics when learning logographic scripts. For example, some Chinese dyslexic children show problems in retrieval of visual information from long-term memory when writing their names in logographic form even though they were familiar with the sound of their names (Ho, Chan, Tsang, Lee, & Chung, 2006). Similarly, Japanese dyslexic children are poor at delayed recall of the Rey–Osterrieth Complex Figure test (ROCF) (Uno, Kaneko, Haruhara, & Kaga, 2000), which taps a component of visual long-term memory. However, our visual long-term memory task minimized the involvement of executive functions (i.e., organization and planning), which are required for the ROCF,

thus demonstrating that visual long-term recognition memory is indeed important in reading and writing logographic Kanji.

The involvement of visual long-term memory in learning to write Kanji should be considered in the light of the close relationship that has been shown between visual long-term memory and sensory-motor representation. A study by Sasaki and Watanabe (1983) demonstrated that the retrieval of familiar Kanji characters was disturbed when finger movements to trace Kanji symbols was prohibited. Furthermore, fMRI studies have shown that both retrieval and writing of well-learned Kanji activated the premotor cortex (Kato *et al.*, 1999), which was also activated by the perception of visually presented Kanji characters (Matsuo *et al.*, 2000) and alphabetic letters (Longcamp, Anton, Roth, & Velay, 2003). These findings suggest that visual representations of characters that are stored in long-term memory may be intimately connected with specific movements that are required for writing them. In fact, Japanese children typically learn to write Kanji characters by repeatedly copying them according to specific stroke orders. Taken together, visual-motor interaction may facilitate memory consolidation for the visual features of Kanji characters and make a specific contribution to learning to write Kanji.

In addition to visual long-term memory, visual short-term memory was a significant predictor of Kanji, but not Kana, performance. This result is in accordance with cross-linguistic studies that show that visual short-term memory is more important for reading in logographic scripts than in phonographic scripts (Everatt, Jeffries, Elbeheri, Smythe, & Veii, 2006; Huang & Hanley, 1995). Although some studies claim that short-term memory and long-term memory are dissociable (Sullivan & Sagar, 1991), the successful transfer of information from short-term memory into long-term memory is crucial for learning in all cognitive modalities. A recent fMRI study has demonstrated a close functional relationship between short-term memory and long-term memory in the visual modality (Ranganath, Cohen, & Brozinsky, 2005): the brain activation in the dorsolateral prefrontal cortex and hippocampus when holding visual information in short-term memory was predictive of successful long-term memory formation. Therefore, good visual short-term memory may lead to good visual long-term memory, which appears to be essential for learning logographic Kanji.

Another important finding was that orthographic processing, measured by the radical position task, was a significant predictor of both Kana and Kanji acquisition. This task was designed to measure children's orthographic knowledge and their visual efficiency for encoding radical position, thus being more visual-orthographic than phonological-orthographic in nature. Similar tasks also predict Chinese reading (Ho, Chan, Lee, Tsang, & Luan, 2004), confirming the importance of visual-orthographic processing in literacy skills in logographic scripts. However, this task used radicals as stimuli, which are constituent elements of Kanji, thus raising the question of its close relationship with Kana writing performance. A possible answer to this question is children's Kana writing was related to their capacity to visually determine the position of the radical within a given character (or pseudocharacter). Indeed, the radical position task was significantly correlated with the visual motion task ($r = -0.47$, $P < 0.01$ from the second graders data and $r = -0.37$, $P < 0.01$ from the full set of data). This is consistent with previous studies, demonstrating that visual motion sensitivity is correlated with orthographic processing in both phonographic (Talcott *et al.*, 2002) and logographic reading (Meng, Zhou, Zeng, Kong, & Zhuang, 2002) as well as with the accurate encoding of letter position (Cornelissen, Hansen, Hutton, Evangelinou, & Stein, 1998). Visual motion sensitivity is a function of the visual magnocellular system, which is thought to be involved in the control of eye movements and attention while reading letters and words sequentially (Stein, 2003). Hence, the visual magnocellular system may contribute

to the development of orthographic processing. Although we found no significant correlation between visual motion sensitivity and literacy measures in logographic Kanji, motion sensitivity was a significant predictor of orthographic processing measured by the radical position task, which was the strongest predictor of Kanji reading.

Auditory-Phonological Skills

Our results also revealed relationships between auditory-phonological skills and literacy performance in Kana and Kanji: low-level auditory processing and phonological awareness predicted only Kana writing, whereas phonological short-term memory predicted all the literacy measures (i.e., Kana writing, Kanji reading, and Kanji writing). Low-level auditory processing is closely related to reading in languages with both regular and irregular orthographies such as Norwegian (Talcott *et al.*, 2003) and English (Talcott *et al.*, 2000), respectively. Similarly, phonological awareness predicts literacy performance, irrespective of the level of orthographic regularity (al Mannai & Everatt, 2005; Caravolas & Volin, 2001; Di Filippo *et al.*, 2005; Nikolopoulos, Goulandris, Hulme, & Snowling, 2006). Kana has an extremely regular orthography, and thus children's typical errors in Kana writing were restricted to the sounds which are specific to Japanese, such as double consonants and contractions, as well as to a few Kana letters with exceptional letter-sound correspondences (i.e., letters with more than two pronunciations). To write these sounds successfully, the children needed to be sensitive to the auditory representations being recognized, to be aware of the phonological representations and then to transcribe them into their visual forms. This error trend in Kana confirms that low-level auditory processing and phonological awareness are important in the acquisition of phonographic scripts, irrespective of the level of orthographic regularity. Educationally, our phonological awareness task, which is based on

mora and involves sounds unique to Japanese, may be a sensitive measure to detect children's literacy problems in Kana.

For Kanji performance, phonological short-term memory was a strong predictor, particularly for reading. Because each Kanji character has different pronunciations depending on the context, it is plausible that the memory capacity to store phonological representations of each Kanji character or word plays an important role in learning to read and write Kanji. In contrast, Kanji performance was neither correlated with the auditory processing task (frequency modulation) nor predicted by phonological awareness. This result is different from previous studies on Chinese acquisition, demonstrating that auditory processing (Meng *et al.*, 2005) and phonological awareness (Ho & Bryant, 1997; Siok & Fletcher, 2001) are related to logographic reading in Chinese. This difference between Chinese and Kanji may be attributed to linguistic differences between Chinese and Japanese. First, Chinese is very tonal, but Japanese is not; hence, sensitivity to auditory stimuli, particularly tones, may be more important for Chinese than for Kanji reading. Secondly, Chinese children use "pinyin," a Romanized phonetic system for learning standard Mandarin Chinese. Pinyin seems to improve phonological awareness in Chinese children, as they performed better at phonological awareness tasks than did Hong Kong Chinese children without pinyin training (McBride-Chang, Bialystok, Chong, & Li, 2004). Hence, phonological awareness is often found to be a significant predictor of Chinese reading. Although further investigation directly comparing Chinese and Japanese Kanji may be necessary, our results for Kanji suggest that phonological awareness has a different significance for different logographic writing systems.

Conclusions

There appear to be differences in the skills that predict literacy performance in

phonographic Kanji and logographic Kanji. Visual memory, particularly long-term memory, makes a strong contribution to the acquisition of logographic Kanji, but not to the learning of phonographic Kana. In contrast, low-level sensory processing (in both auditory and visual modalities) and phonological awareness play important roles in Kana but not in Kanji acquisition. In addition, phonological short-term memory and orthographic processing may be essential for literacy acquisition, regardless of the script or language. Educationally, our results suggest that children's literacy problems and remediation programs should be considered in the context of the script in which children are learning to read and write.

Conflicts of Interest

The authors declare no conflicts of interest.

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